NORTH CAROLINA
DEPARTMENT OF WATER RESOURCES

DIVISION OF GROUND WATER

REPORT OF INVESTIGATIONS NO. 2

GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA

PART 2

By

JOEL O. KIMREY

RALEIGH, NORTH CAROLINA

1960

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DEPARTMENT OF WATER RESOURCES

Harry E. Brown, *Director*

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Harry M. Peek, *Chief*

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JOEL O. KIMREY

U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

in cooperation with the

NATIONAL PARK SERVICE

RALEIGH, NORTH CAROLINA

1960

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The Honorable Luther H. Hodges
Governor of North Carolina
Raleigh, North Carolina

Dear Governor Hodges:

I am pleased to submit Report of Investigations No. 2, "Ground-Water Supply of Cape Hatteras National Seashore Recreational Area, Part 2," prepared by Mr. Joel O. Kimrey, United States Geological Survey, in cooperation with the National Park Service.

This report gives the results of the second phase of intensive studies by the Geological Survey to evaluate and aid in the development of ground-water supplies in the Seashore Recreational Area. It presents the data collected at Fort Raleigh National Historical Site, Oregon Inlet Campground, Pea Island Campground, Chicamacomico Station, Little Kinnakeet Station, the Cape Point Area, the Hatteras Inlet proposed campground site, and Ocracoke Island proposed campground site, and the Ocracoke Docks Campground.

Respectfully submitted,

Harry E Brown

Harry E. Brown

CONTENTS

Illustrations

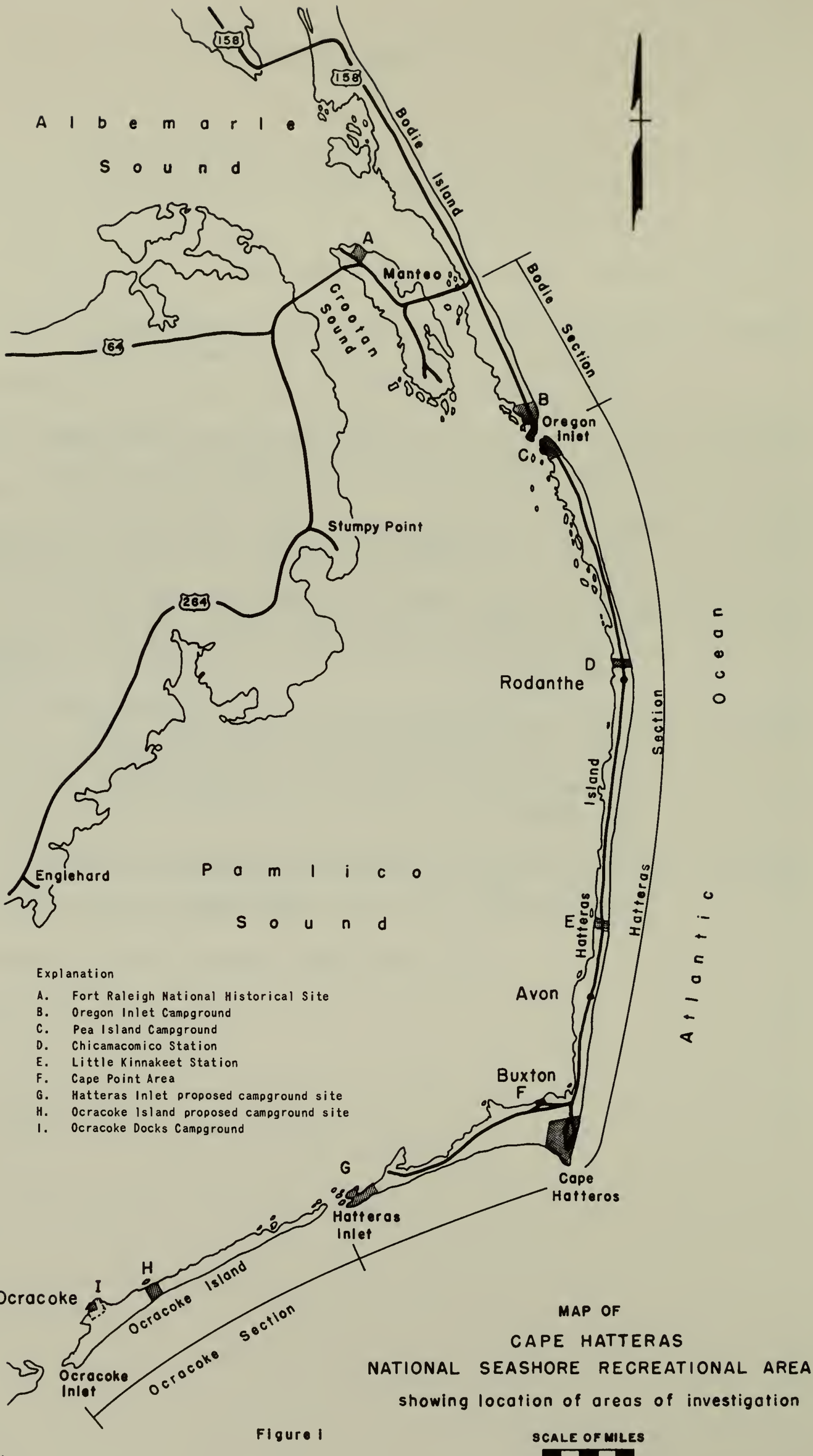

158
Albemarle
Sound
Bodie Island
A
Manteo
Bodie Section
Croatan Sound
64
B
Oregon Inlet
C
Stumpy Point
264
D
Rodanthe
Ocean
Island
Section
Englehard
Pamlico
Sound
E
Hatteras
Hatteras
Atlantic
Avon
Explanation
A. Fort Raleigh National Historical Site
B. Oregon Inlet Campground
C. Pea Island Campground
D. Chicamacomico Station
E. Little Kinnakeet Station
F. Cape Point Area
G. Hatteras Inlet proposed campground site
H. Ocracoke Island proposed campground site
I. Ocracoke Docks Campground
Buxton
F
G
Cape Hatteras
Hatteras Inlet
H
I
Ocracoke
Ocracoke Island
Ocracoke Section
Ocracoke Inlet
MAP OF
CAPE HATTERAS
NATIONAL SEASHORE RECREATIONAL AREA
showing location of areas of investigation
SCALE OF MILES
0
5

Figure I

GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA

Part 2

By

Joel O. Kimrey

INTRODUCTION

In 1957, the National Park Service requested the aid of the U. S. Geological Survey to determine if an adequate ground-water supply could be obtained at previously selected sites within the Cape Hatteras National Seashore Recreational Area (fig. 1). As the first phase of compliance with this request a report entitled "Ground-Water Supply of Cape Hatteras National Seashore Recreational Area" by P. M. Brown, Ground Water Branch, U. S. Geological Survey, was prepared and transmitted to the National Park Service in 1958.

The current report, prepared under the general supervision of P. E. LaMoreaux, Chief, Ground Water Branch, and under the immediate supervision of P. M. Brown, District Geologist, Ground Water Branch, presents an evaluation of available ground-water supplies at additional sites for which information was requested by the National Park Service in 1957. These sites are (fig. 1) Fort Raleigh National Historical Site, Oregon Inlet Campground, Pea Island Campground, Chicamacomico Station, Little Kinnakeet Station, the Cape Point Area, the Hatteras Inlet proposed campground site, the Ocracoke Island proposed campground site, and the Ocracoke Docks Campground.

Field work for the investigation, accomplished during the first three months of 1959, consisted of a test-drilling program to determine the depth to salt water and the areal extent, physical characteristics, and water-bearing properties of the unconsolidated sediments underlying the test sites.

The writer wishes to acknowledge the generous assistance of Mr. Robert Gibbs, Superintendent, Cape Hatteras National Seashore Recreational Area, and personnel attached to Mr. Gibbs's staff who assisted with the collection of field data.

GEOGRAPHY

The Cape Hatteras National Seashore Recreational Area, North Carolina, is on a group of coastal islands known as the "outer banks." These islands, forming the eastern rim of the State, are barrier beaches that separate the Atlantic Ocean to the east from the various sounds to the west. Park facilities extend for some 77 miles along these barrier beaches and occupy a part of three islands - Bodie, Hatteras, and Ocracoke (fig. 1).

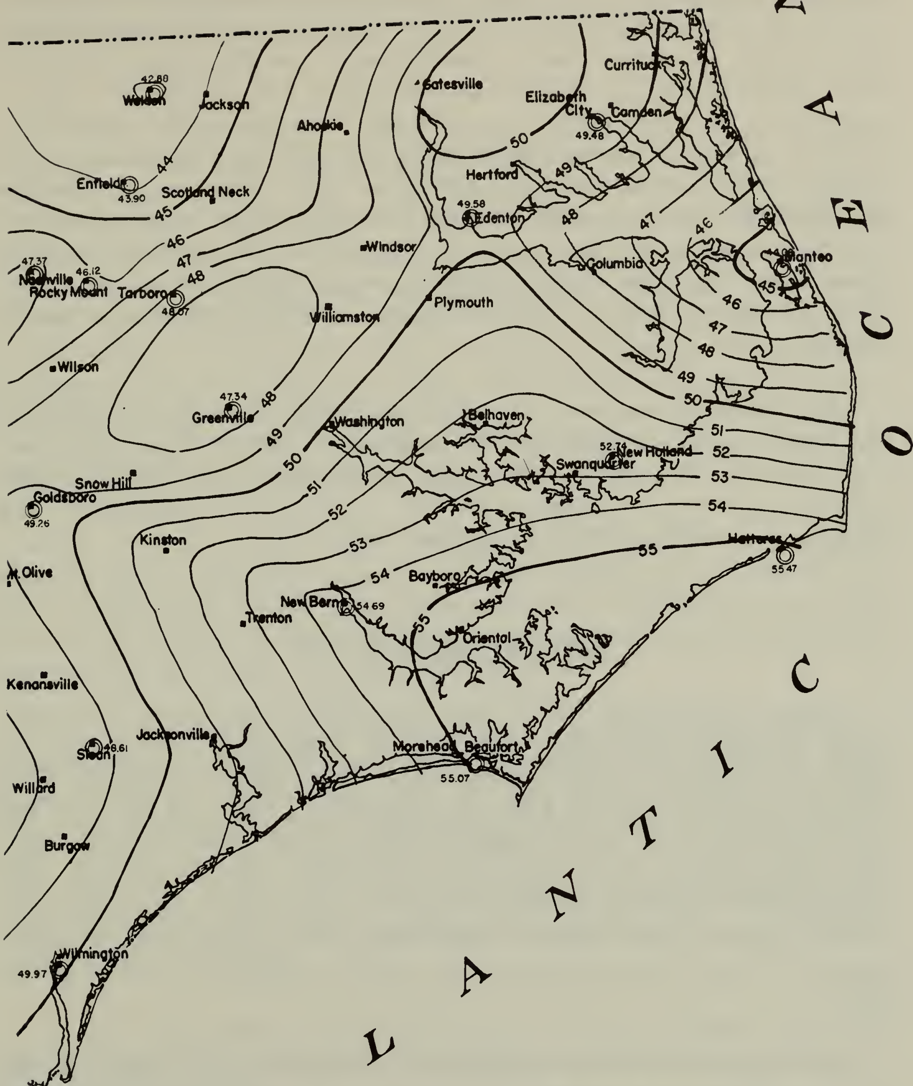
Shifting sand dunes blanket these islands in areas not stabilized by vegetation. Sand dunes generally border the ocean beaches, and tidal marshes occur on the sound-side of the islands. The islands comprising the Park facilities range in width from a maximum of about 3 miles at Cape Hatteras to a minimum of less than a quarter of a mile along stretches of Hatteras and Ocracoke Islands. Elevations vary from sea level in the sound-side marshes to as much as 60 feet above sea level on some dunes.

Average precipitation ranges from 44.05 inches at Manteo to 55.47 inches at Hatteras (fig. 2), being greatest between July and October. The surface sands of the area have high permeabilities and absorb rainfall rapidly. If surface runoff occurs, it is probably confined to the tidal marshes bordering the sounds. Rainfall moves directly downward to the water table, then discharges by lateral seepage to the ocean and the sounds.

GROUND WATER

Ground water is the water that occurs in the zone of saturation -- the zone in which all pore spaces are filled with water. An aquifer is a formation, part of a formation, or group of formations that are water bearing.

When precipitation reaches the land surface, part of it runs off on the surface to streams and lakes, part evaporates from the surface, and part soaks into the ground. Of the part that soaks into the ground, some is transpired by plants or is evaporated from the soil. The remainder continues downward under the influence of gravity to the top of the zone of saturation which is called the water table. Water in the zone of saturation moves laterally to a place of discharge such as a well or a spring. The later movement of water in an aquifer may take place either under nonartesian or artesian conditions. Where ground water does not completely fill a



North Carolina

State Board of Water Commissioners

AVERAGE ANNUAL RAINFALL

1921-1955

Scale in Miles

10 0 10 20 30 40

Figure 2

permeable formation, its surface, which is at atmospheric pressure, is free to rise and fall. Such ground water is said to occur under nonartesian, or water-table, conditions, and the water level in wells penetrating this formation represents the top of the zone of saturation, or water table, at any time. If ground water completely fills a permeable formation that is overlain and underlain by a relatively impermeable bed or aquiclude, its surface is not free to rise and fall and the water is said to occur under artesian conditions. The water levels in wells penetrating an artesian aquifer stand above the base of the confining bed. The height of the water level is determined by the hydrostatic pressure in the artesian aquifer.

All fresh ground water in the Cape Hatteras area, at least to the depths penetrated by test wells drilled during this investigation, occurs under water-table conditions and is derived from the precipitation on the areas. Rainfall is soaked up rapidly in the area by the highly permeable surface sands.

Saline Contamination

Fresh ground water in the Cape Hatteras area occurs as a lens lying on top of salt water. Recharge of fresh water to the lens is by precipitation. Withdrawal of this fresh water in excess of a given amount may result in the encroachment of salt water into the fresh-water aquifer being pumped. Such encroachment is dependent upon the depth and location of wells, their rate of pumping, the elevation of the water table relative to sea level, and other pertinent factors that must be considered prior to determining the amount of fresh water that may be safely withdrawn from a given area.

The theoretical static relationship concerning the depth to the fresh-salt-water interface is expressed by the Ghyben-Herzberg equation as follows:

$$Z = \frac{Pf}{Ps - Pf} hf$$

where Z = depth of fresh water below sea level

Ps = density of sea water (ordinarily about 1.025 $\frac{\text{grams}}{\text{cm}^3}$)

Pf = density of fresh water (considered to be 1 $\frac{\text{gram}}{\text{cm}^3}$)

hf = head of fresh water above sea level

Substitution of the above listed values for Ps and Pf simplifies the equation to:

$$Z = 40\ hf$$

This form of the equation indicates that for every foot of fresh-water head above sea level there is about 40 feet of fresh water below sea level. Salt water of density differing from 1.025 $\frac{grams}{cm^3}$ would, of course, give a Z value differing from 40. But the 40 to 1 ratio is used in theoretical assumptions here because it has been assumed that 1.025 $\frac{grams}{cm^3}$ is the most probable value for the density of sea water in the area. Brown[1] pointed out that the Ghyben-Herzberg principle "appears to apply particularly to small islands and narrow land masses that are made up of freely pervious material, especially sand." Therefore it would be expected to apply rather closely in the Cape Hatteras area (fig. 3).

Measurement of the water levels in test wells in the Cape Hatteras area indicated a fresh-water head ranging from less than a foot to more than 9 feet above mean sea level. Application of the 40 to 1 ratio gives a depth to salt water ranging from less than 40 feet to more than 360 feet below sea level.

Determinations of chloride content of water samples from test wells, however, indicate that the thickness of the fresh-water lens is less than the theoretical value at many well locations. In some wells the chloride content decreased somewhat with depth, and in other wells zones of relatively saline water were interstratified with zones of fresh water. This difference between theoretical values and field data may be explained by one or more of the following modifying factors.

1. The wide range in permeabilities of the sediments tend to negate the establishment of a condition of equilibrium between fresh and salt water.

2. Sufficient time may not have elapsed to allow the fresh-salt-water system to have reached a stage of dynamic equilibrium.

3. Occasional inundation of the land mass by high tides has resulted in a stratification and mixing of fresh and salt water.

[1] Brown, J. S. A study of coastal ground water, with special reference to Connecticut, U. S. Geol. Survey Water Supply Paper 537, pp. 16-17, fig. 2, 1925.

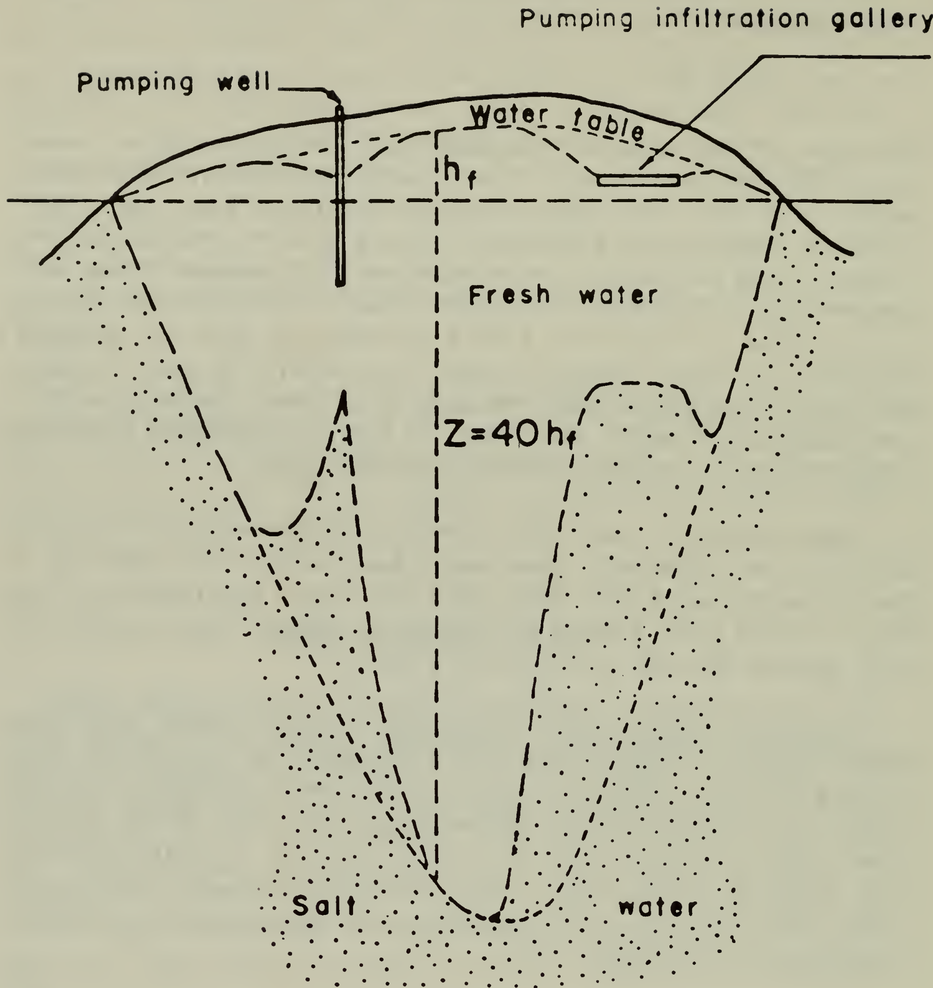


Diagram showing the theoretical relation of fresh water to salt water in a sandy island under pumping conditions

Figure 3

4. Near the beaches a zone of diffusion rather than a sharp interface exists as a result of the mixing action of tidal forces.

The modifying effects of the above factors as they relate to specific sites in the Cape Hatteras area will be mentioned later in the report.

Quantitative Ground-Water Studies

The withdrawal of water from an aquifer causes water levels to decline in the vicinity of the point of withdrawal. It has been pointed out in the discussion of salt-water encroachment that the height of the water table above sea level in the area is the primary factor that will determine whether salt-water encroachment will occur as a result of withdrawal. The amount by which water levels may be lowered by pumping is governed by several factors which include (1) the rate of pumping, (2) the boundaries of the aquifer, (3) the water-transmitting and water-storage characteristics of the aquifer, and (4) the conditions under which the aquifer is recharged with water and under which water discharges from it.

Aquifers function in two capacities -- as conduits to transmit water and as reservoirs to store water. The measure of an aquifer's ability to transmit water is its coefficient of transmissibility, which is defined as the rate of flow of water, in gallons a day at the prevailing water temperature, through each vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer, under a unit hydraulic gradient. The measure of an aquifer's ability to store water is its coefficient of storage, which is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The determination of approximate values for these two coefficients is a part of almost all quantitative ground-water studies. When they have been determined, they may be used to estimate the decline in water levels caused by pumping.

PURPOSE AND METHODS OF INVESTIGATION

The Cape Hatteras National Seashore Recreational Area is on elongate, narrow islands that are surrounded by the salty waters of the Atlantic Ocean and Pamlico Sound. In such an area three possible sources of salt-water encroachment are: (1) lateral encroach-

ment from the ocean or sound (2) vertical encroachment from beneath the fresh-water lens (3) overland encroachment from inundation of the surface by salty water during storms.

This investigation was designed to evaluate the ground-water resources in certain areas where the Cape Hatteras National Seashore Recreational Area has or proposes to construct facilities. The evaluation includes data on the lithology of the water-bearing materials of the areas, the vertical and lateral extent of fresh-water bodies; and at selected locations, quantitative data concerning the potential yield of the aquifer of an area so as to prevent lateral and vertical encroachment of salt water into the fresh water aquifers.

To obtain the necessary data, test wells were drilled with a power auger. Rock samples were collected at five-foot intervals from these wells. Water samples were collected from the lithologic units penetrated in each well. The chloride content of all water samples was determined by field tests, and field chloride results were later compared with laboratory analyses made by the Quality of Water Branch, U. S. Geological Survey. Ostracodes and foraminifers identified in the well cuttings indicate a Recent age for all the sediments penetrated by the test wells. Chloride contents of water samples and rock samples from all test wells are on file at the office of the Ground Water Branch, U. S. Geological Survey, Raleigh, North Carolina.

The individual areas of investigation are shown in figure 1. The test-drilling and water-sampling data indicated that three areas are potential sources of ground-water supply. Pumping tests were conducted in two of these areas, the Cape Point Area and the proposed campground area on Ocracoke Island, in order to make quantitative estimates of their ground-water potential. The third area, the Fort Raleigh National Historical Site, is to receive more detailed investigation in 1960.

GROUND-WATER SUPPLY SYSTEMS

Ground-water supplies from water-table aquifers endangered by salt-water encroachment may be obtained from shallow wells and/or infiltration galleries. A discussion of these types of ground-water supply systems in relation to their use in the Cape Hatteras National Seashore Recreational Area follows.

Shallow wells offer the advantage of ease of installation. They may be driven, jetted, bored, or drilled to the desired depth. If a supply area is contaminated by salt-water encroachment, the shallow-well system may be moved to an uncontaminated supply area relatively easily.

The major disadvantage of using shallow wells in an area endangered by salt-water encroachment is the continuing regulation of the pumping rate of each well. It has been previously mentioned that the height of the water table above sea level in a supply area is the primary factor that determines whether or not salt-water encroachment will occur as a result of the withdrawal of fresh water. Salt water may encroach if the water level in one or more wells in a supply area is drawn down below sea level. Water-table aquifers respond rapidly to changes in discharge or recharge; this may require that the pumping rate be adjusted frequently to maintain the pumping level in supply wells above some predetermined maximum drawdown. For example, during a period of frequent recharge by rainfall, the water table in the area would be relatively high and more water could be withdrawn from each well without exceeding the predetermined maximum drawdown than could be withdrawn during a period of less recharge by rainfall because of the resultant lower water table in the area.

Infiltration galleries in unconsolidated material usually are constructed by laying perforated pipe, tile, etc. horizontally in trenches below the water table. The trenches are back filled, often with gravel, and the perforated pipe permits water to be pumped from these "horizontal wells."

Properly installed infiltration galleries eliminate the danger of vertical salt-water encroachment. For example, if an infiltration gallery is laid at a depth of 2 feet above sea level, the water table at the gallery cannot be drawn down, by pumping the gallery, below 2 feet above sea level. This 2 feet of fresh water head above sea level is sufficient to prevent vertical salt-water encroachment into the fresh-water supply.

The major disadvantage of an infiltration-gallery system is the difficulty of installation as compared with the installation of a shallow-well system. For example, if infiltration galleries were installed in the dune areas covered by this report, a trench, 15 to 20 feet deep, might be required to install them at the proper level because the water table is that depth below land surface, in the dunes. Caving of the dune sands into a trench of this depth would

make installation very difficult. Their installation would, of course, be simpler in areas where the water table was closer to the land surface. Once installed, infiltration galleries also are more difficult to relocate than shallow wells if the supply area is ruined by overland or lateral salt-water encroachment.

Perhaps ground-water systems might be made up of both infiltration galleries and wells if neither type system alone can supply the desired amount of water. The infiltration galleries might be installed in areas where the water table is near the land surface and where there is little danger of overland salt-water encroachment by storm tides; the wells might be installed in dune areas where the water table is deeper below the land surface or in areas where there is danger of overland salt-water encroachment.

GROUND-WATER SUPPLIES IN SPECIFIC AREAS

Fort Raleigh National Historical Site

Fort Raleigh is near the northwest end of Roanoke Island (fig. 1). It is the location of the first English colonization attempts in this country in 1585 and 1587.

The site, some 18½ acres in area, is forested and ranges in altitude from 15 feet to more than 20 feet above mean sea level. Ground water drains to the north into Albemarle Sound.

Ground water is used for drinking purposes by Park Service personnel and visitors to the area. Water consumption is greatest during the summer months owing to the greater number of visitors. Present ground-water supplies are obtained from shallow wells.

Three test wells, 128 feet deep, were drilled at Fort Raleigh. They were located in a triangular pattern - 2 wells were drilled on the north side of the area adjacent to Albemarle Sound and the other near the southern limits of the site (pl. 1). Correlation of the rock material from the test wells shows that 4 lithologic units are identifiable in the area as follows:

	Depth (in feet below land surface)	Thickness (in feet)
Medium to fine-grained quartz sand containing clay-sized material in the upper 5 feet. Quartz grains have frosted surfaces.	0-15	15

Coarse to medium-grained quartz sand containing shell fragments and gravel in the lower 10 feet.	15-40	25
Fine-grained silty sand containing disseminated shell fragments. Silt content increases with depth. Shell fragments are concentrated in thin layers.	40-110	70
Clay and fine-grained silty sand. Clay layers ranging in thickness from 2 - 3 inches to 5 feet interbedded with silty sand.	110-128	18+

The depths and thicknesses given above are approximate as they represent averages based on samples collected from the three test wells drilled in the area.

Water-level measurements in the test wells show that the freshwater head ranges from 3 to more than 4 feet above mean sea level. Water samples were not collected below a depth of 80 feet because of the impermeability of the material. The chloride content of the water from the three test wells ranged from 26 to 34 ppm. There is no apparent increase in the chloride content of the water from the test wells with depth.

Fort Raleigh is in a protected area that is seldom, if ever, flooded. Thus there is little danger of salt-water contamination of the fresh ground water by inundation. The relatively impermeable clayey zone that occurs below a depth of 110 feet below land surface should prevent vertical encroachment of salt water. However there is little difference in the lateral permeability of the sands underlying the area. Thus lateral encroachment of salt water may occur if a well in the area were pumped until its drawdown reduced the head between the well and the salt-water body enough to induce salt-water encroachment above the clay layers.

If additional supply wells are constructed at Fort Raleigh, they should be on the south side of the site thereby lessening the danger of lateral encroachment of salt water. Wells should not be more than 40 feet deep so that they may withdraw water from the coarse sand that occurs between the depths of 15 and 40 feet.

Infiltration galleries on the south side of the site might also be considered as a source of future water supply. Water-level measurements in the test wells indicate that they must be placed at a

depth of about 15 feet below land surface in order to lie beneath the water table. In no event should they be laid at a depth lower than 1 foot above sea level.

Quantitative estimates of the amount of water that may be safely withdrawn from each well or infiltration gallery cannot be made until a pumping test has been conducted in the area.

Oregon Inlet Campground

The Oregon Inlet Campground is on the southern tip of Bodie Island (fig. 1). The area is bordered on the east by the Atlantic Ocean, on the west by Pamlico Sound, and on the south by Oregon Inlet which separates Bodie and Hatteras Islands.

Shifting sand dunes as much as 30 feet high border the ocean, whereas marshes border Pamlico Sound. Low sand flats lie between the sand dunes. Ground water drains into the ocean, the sound, and the inlet.

Present ground-water supplies are obtained from shallow, sand-point wells in the dune areas bordering the ocean. Water is used for sanitary and domestic facilities by campers and visitors.

Eight test wells in three roughly parallel lines extending from the ocean beach to the soundside marshes were drilled in the Oregon Inlet Campground area (pl. 1). The depth of these wells ranged from 38 to 108 feet below land surface. The sediments penetrated by the test wells may be divided into two lithologic units that are identifiable over all the area covered by drilling.

The upper unit is composed of clean, medium to fine-grained quartz sand that usually contains disseminated shell fragments and traces of gravel in its lower ten feet.

The lower unit is a silty sand which was first penetrated in each test well at depths ranging between 30 and 40 feet below land surface. The amount of silt usually increases with depth in this unit. Lenses of clean sand and discontinuous layers of clay in this unit make lateral correlation difficult.

Water-level measurements in the Oregon Inlet Campground test wells indicated a fresh-water head ranging from less than a foot to more than 4 feet above mean sea level. In this area wells did not yield fresh water from a depth greater than 30 feet below land sur-

face. The chloride content of water from wells in this area ranged as high as 17,800 ppm.

The low sand flats between the dunes on the ocean side and the marshes on the sound side of the area are occasionally flooded by high waters. Test wells drilled in these low areas yielded salty water from the water table downward. Thus it appears that sufficient time does not elapse between inundations to permit the flushing of the saline water from the aquifer by precipitation. The test wells that yielded fresh water to a depth of thirty feet were at high elevations on the flanks of dunes.

The above data indicate that no large supply of fresh ground water is available in the Oregon Inlet Campground area. The only sources of fresh water in the area indicated by test drilling are the small lenses of fresh water that occur beneath the dunes.

Pea Island Campground

Pea Island Campground is on the northern tip of Hatteras Island (fig. 1). The campground is in a dune area that is bordered on the east by the Atlantic Ocean and on the north by Oregon Inlet. A flat, grassy area west of the campground extends to Pamlico Sound.

The dunes in the campground area are as much as 30 feet high. The low areas between the dunes are only a few feet above sea level. Ground water drains into the ocean, the inlet, and the sound.

Present ground-water supplies are obtained from shallow, sand-point wells in the dunes bordering the ocean. Water is used for sanitary and domestic facilities by campers and visitors.

Ten test wells in three roughly parallel lines extending from the ocean beach to the flat area adjoining the sound were drilled in the Pea Island Campground area (pl. 1). The depth of these wells ranged from 43 to 108 feet below land surface. Data gained from these test wells indicate that geologic and hydrologic conditions at the Pea Island Campground are very similar to those at Oregon Inlet Campground. The sediments penetrated by the test wells may be divided into two lithologic units that are identifiable over all of the area covered by drilling.

The upper unit is composed of clean, medium to fine-grained

quartz sand that usually contains disseminated shell fragments and traces of gravel in its lower ten feet.

The lower unit is a silty sand which was first penetrated in each test well at depths ranging between 25 and 40 feet below land surface. Lenses of clean sand and occasional layers of clay in this unit make lateral correlation difficult. The amount of silt usually increases with depth in this unit.

Water-level measurements in the Pea Island Campground test wells indicated that the height of the water table above mean sea level ranged from less than a foot to about 5 feet. No wells in this area yielded fresh water from a depth greater than 30 feet below land surface. The chloride content of water from test wells in this area ranged as high as 42,600 ppm.

The low areas between the dunes are occasionally flooded by high waters. Test wells drilled in these low areas yielded salty water from the water table downward. Thus it appears that sufficient time does not elapse between inundations to permit the flushing of the saline water from the aquifer by precipitation. The test wells that yielded fresh water to a depth of 30 feet were at high elevations on the flanks of dunes.

The above data indicate that no large supply of fresh ground water is available in the Pea Island Campground area. The only sources of fresh water in the area indicated by test drilling are the small lenses of fresh water that lie beneath the dunes.

Chicamacomico Station

Chicamacomico Station is in the village of Rodanthe on Hatteras Island (fig. 1). The station is an old Coast Guard facility that is currently being used to house National Park Service personnel.

Hatteras Island is narrow and relatively flat at Rodanthe. The altitude of the village averages about 5 feet above mean sea level, and the island is about ½ mile wide at this point. Ground water drains into the Atlantic Ocean and Pamlico Sound. Chicamacomico Station is approximately midway between ocean and sound.

Water is used for domestic purposes by the inhabitants of the Station. Water supplies are currently obtained from cisterns and shallow, sand-point wells.

Three test wells were drilled in a line from ocean to sound at Chicamacomico Station (pl. 1). The depth of these wells ranged from 48 to 108 feet below land surface. The deposits penetrated by the test wells may be divided into 2 lithologic units.

The upper unit is composed of clean, medium to fine-grained quartz sand that contains coarse well-rounded gravel and shell fragments. The coarse gravel and percentage of shell in the upper unit ranges between 5 and 50 percent.

The lower unit is a medium to fine-grained sand that contains disseminated shell fragments and up to 15 percent silt. It was penetrated in each test well at a depth of about 45 feet.

The water table at Chicamacomico Station is about 2 feet above mean sea level as indicated by water-level measurements in the test wells. Wells in this area did not yield fresh water from a depth greater than 20 feet below land surface. The highest chloride content in water samples from these test wells was 4,590 ppm. This section of the island is low, flat, and relatively unprotected from flooding by high water. The test-drilling program indicates that no large supply of fresh ground water is available in the Chicamacomico Station area.

Little Kinnakeet Station

Little Kinnakeet Station is about 4 miles north of the village of Avon on Hatteras Island (fig. 1). The station is an old Coast Guard facility that is now used by the National Park Service to house employees.

The elevation of Little Kinnakeet Station averages about 5 feet above mean sea level; this section of the island is relatively flat and has a width of about ½ mile. Ground water drains into the Atlantic Ocean and Pamlico Sound.

Water supplies are currently obtained from shallow, sand-point wells and are used for domestic purposes by the inhabitants of the Station.

Three test wells were drilled in a line from ocean to sound at Little Kinnakeet Station (pl. 1). The depths of these wells ranged from 33 to 103 feet below land surface. The test wells indicate that this area is very similar hydrologically to the Chicamacomico Station area. The deposits penetrated by the test wells may be divided into 2 lithologic units.

The upper unit is composed of medium to fine-grained quartz sand that contains disseminated shell fragments and traces of small gravel.

The lower unit is composed of 65 percent coarse to medium-grained quartz sand, 20 percent coarse shell fragments mixed with gravel, and 15 percent silt. It was penetrated in all test wells at an average depth of 30 feet below land surface.

The water table at Little Kinnakeet Station is about 2 feet above sea level as indicated by water-level measurements in the test wells. Wells in this area did not yield fresh water from a depth greater than 13 feet below land surface. The highest chloride content in water from these test wells was 4,540 ppm. The area surrounding the station is flat, low in elevation, and relatively unprotected from inundation by storm waters. The test-drilling data indicate that no large supply of fresh ground water is available in the Little Kinnakeet Station area.

Hatteras Inlet proposed campground site

The proposed camping area at Hatteras Inlet is near the southern end of Hatteras Island (fig. 1). The area is bounded on the east by the Atlantic Ocean, on the west by Pamlico Sound, and on the south by Hatteras Inlet which separates Hatteras and Ocracoke Islands.

The proposed camping area is narrow and flat; its average altitude is less than 4 feet above mean sea level. At present, no wells produce fresh water at the proposed camp site. Ground water drains into the ocean, the sound, and the inlet.

One test well, 98 feet deep, was drilled at the site of the proposed campground (pl. 1). Three lithologic units are identifiable in the rock cuttings obtained from this well as follows:

	Depth (in feet below land surface)	Thickness (in feet)
Medium to fine-grained quartz sand containing traces of small shell fragments and travel.	0-65	65
Fine-grained quartz sand interbedded with indurated shell beds up to 6 inches in thickness.	65-75	10
Medium to fine-grained silty sand.	65-98	33+

The chloride content of the water from this test well indicated salty water from the water table downward. The highest chloride content in water from this well was 13,000 ppm.

The Hatteras Inlet area is often exposed to flooding from both the ocean and the sound. The test well was drilled at a location that is more protected from inundation than the surrounding area. Data obtained from this test well indicate that no appreciable fresh ground-water supply is available at the proposed campground site.

Ocracoke Docks Campground

The Ocracoke Docks Campground is in the village of Ocracoke near the southern end of Ocracoke Island (fig. 1).

The Campground occupies a flat, exposed area, about five feet above mean sea level, which fronts on Pamlico Sound. The Campground area drains into Pamlico Sound. Cisterns and shallow, sand-point wells are used to obtain water in and around the village of Ocracoke.

Three test wells were drilled in a triangular pattern at Ocracoke Docks (pl. 1). One well was located adjacent to the edge of the sound; 2 wells were drilled inland from the sound's edge. The depth of these wells ranged from 48 to 83 feet below land surface. Three lithologic units are identifiable in the deepest test well as follows:

	Depth (in feet below land surface)	Thickness (in feet)
Fine-grained silty sand.	0-9	9
Medium to fine-grained quartz sand containing disseminated shell fragments.	9-75	66
Fine-grained clayey sand.	75-83	8+

The upper two units described above were penetrated by all the test wells.

Water samples from the test well nearest the sound showed salty water throughout the depth penetrated by the well. One of the wells drilled inland from the sound yielded fresh water to a depth of 35 feet below land surface; the other well drilled inland from the

sound yielded fresh water to a depth of 25 feet. The highest chloride content in water samples from these wells was 17,400 ppm.

Parts of the Ocracoke Docks Campground are frequently flooded by high wind tides. The above data indicate that no appreciable supply of fresh ground water is available in this area.

Ocracoke Island proposed campground site

The proposed campground site on Ocracoke Island is about three miles northeast of the village of Ocracoke (fig. 1). At this point the island is about 3/4 miles wide. Sand dunes which range as high as 40 feet occupy the center of this section of the island. These dunes are partly protected from erosion by vegetation. A flat plain southeast of the dunes borders the Atlantic Ocean and marshes northwest of the dunes border Pamlico Sound. Ground water drains into the ocean and sound.

Six test wells were drilled near the proposed Ocracoke Island campground site on the relatively high ground which surrounds the dunes in the center of the island (pl. 1). One test well was 103 feet deep; the other 5 wells were 53 feet deep.

All the test wells penetrated an upper unit composed of clean, medium to fine-grained quartz sand containing disseminated shell fragments. The deepest well (103 feet) penetrated a clayey sand at a depth of 95 feet below land surface; this clayey sand was not penetrated by the other wells.

The chloride content of water samples from these wells indicates that fresh water extends to a depth of about 45 feet below land surface. The sharpness of the fresh-salt water interface is shown by comparison of the chloride content of water samples taken from the depth intervals of 45-48 and 50-53 feet in one well. The chloride content of water from the 45-48 feet interval was 199 parts per million, whereas the chloride content of water from the 50-53 feet interval water sample was 2,590 ppm. The highest chloride content in water samples taken from the test wells in this area was 16,100 ppm; this sample was taken from 70 feet below land surface.

The altitude of the water table in this area averages about 5 feet above mean sea level as shown by water-level measurements in the test wells. The thickness of the fresh water lens below sea

level in this area is about 40 feet. However, application of the Ghyben-Herzberg principle would indicate 200 feet of fresh water below sea level. This discrepancy between theoretical and field data may be explained by the fact that the surrounding lowlands, large in area in comparison to the size of the dune area, are occasionally flooded by high storm tides. Apparently, sufficient time does not elapse between inundations to permit the fresh water lens to approach its maximum theoretical thickness.

A pumping test was conducted March 17 to 18, 1959, in an area where the fresh-salt water interface was about 50 feet below land surface when pumping began. Five wells were constructed in the area (pl. 1); one production well (P-a) that was 27 feet deep, three observation wells (O-a, b, and c), each 27 feet deep, for measuring the drawdown in water levels caused by pumping, and one chloride-observation well (O-d), 47 feet deep, to measure the increase in chloride content caused by pumping.

The production well (P-a) was pumped at a steady rate of 30 gpm for 20 hours. At the beginning of the pumping test the chloride content of water from the production well was 32 ppm, and varied between 32 and 36 ppm during the first 10 hours of pumping. After 10 hours of pumping the chloride content of the water from this well showed a steady increase, until it reached 333 ppm at the end of 20 hours.

The chloride content of water from the chloride-observation well (O-d) was 84 ppm when pumping began. At the end of 4 hours of steady pumping the chloride content of the water had increased to 318 ppm. At the end of 20 hours the chloride content had increased to about 10,500 ppm. The pumping test ended after 20 hours of steady pumping.

The altitude of the water level in the production well was 5.05 feet above mean sea level before pumping began. Steady pumping for 20 hours at the rate of 30 gpm, caused a drawdown in the production well of 9.82 feet (to altitude 4.77 feet below mean sea level). The drawdown for the rate of pumping in the production well was greater than that expected from comparison with drawdown data obtained by the U. S. Geological Survey from a pumping test conducted with a well that yielded water from a similar aquifer on Bodie Island.

The fresh-salt-water interface is in a permeable homogeneous sand. As a result this interface is free to rise or fall in response to changes in the elevation of the water table. During the

pumping test the lowering of the water table to 4.77 feet below mean sea level was sufficient to cause vertical salt-water encroachment and contamination of the production well.

Evaluation of the pumping-test data for the proposed Ocracoke Island Campground Area indicates that vertical supply wells should be shallow and their yield controlled within narrow limits in order to prevent vertical encroachment of salt water. Difference in relief would require that infiltration galleries be buried about 20 feet, and yield would be limited by the recharge and the area drained by the galleries. Galleries placed above sea level would not be subject to contamination by salt water, but caving of dune sands may make construction difficult. In developing a water supply using vertical wells in the area consideration should be given to the following suggestions:

1. Individual supply wells should be spaced at least 75 feet apart and should be no deeper than 10 feet below mean sea level.

2. The yield from each supply well should be limited (about 10 gpm according to the pumping-test data) so that the pumping water level will not fall below an elevation of 1 foot above mean sea level.

3. An observation well should be constructed in the supply area at least 150 feet from the nearest supply well. Water-level measurements in this well should be recorded at least weekly, correlated with the amount of drawdown occurring in the supply wells, and, in conjunction with pumping water levels, be used to regulate the pumping rate of the supply wells.

4. A chloride monitor well should be constructed in the supply area and screened between 25 and 35 feet below mean sea level. The chloride content of water from this well should be determined weekly.

Cape Point Area

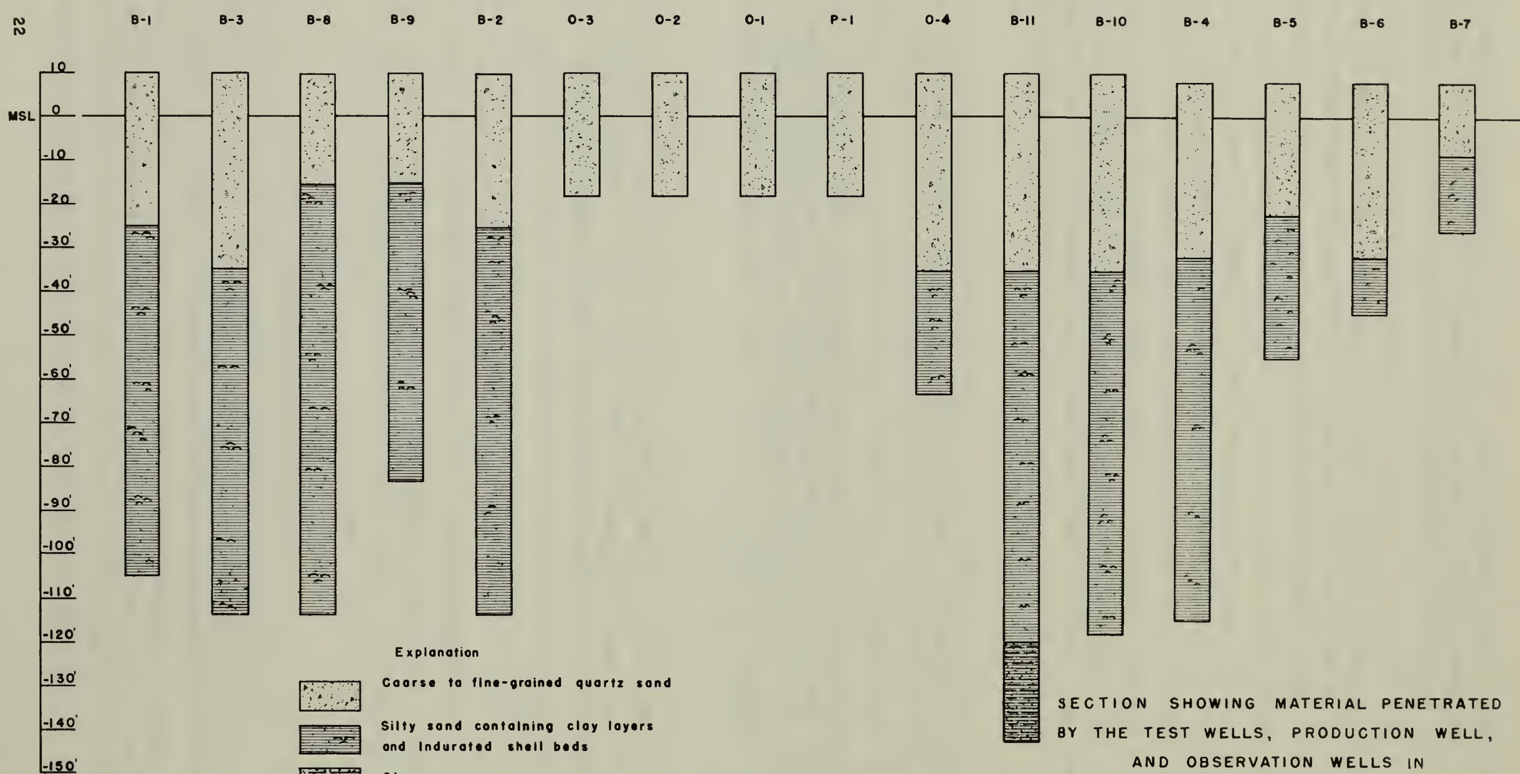
The Cape Point Area (fig. 1 and pl. 2) lies between Cape Hatteras and the village of Buxton on Hatteras Island. National Park Service facilities within this area include a museum, a maintenance area, quarters for personnel, and a large campground at Cape Point. A limited supply of ground water, currently obtained from shallow driven wells, is used for sanitary and domestic purposes.

Hatteras Island makes a sharp bend at Cape Hatteras where its general alignment shifts from a north-south to east-west direction. The island reaches its maximum width of about 3 miles adjacent to the Cape Point Area. The area of investigation has the shape of a quadrilateral whose eastern and southern sides border the Atlantic Ocean. The area is a flat, grassy plain that is bordered on its northern side by forest-covered dunes. The dunes range in altitude up to 37 feet above mean sea level, and trend almost east-west. The flat plain, with an average altitude of about 10 feet above mean sea level along its northern and northwestern limits, slopes gently southeastward to an altitude of 6 to 8 feet above mean sea level near the ocean. Seasonally, fresh-water swamps and ponds form in portions of this plain because of the periodic high water table in the area and the flat surface drainage toward the ocean. Ground water drains into the ocean and there is little, or no, surface runoff.

Eleven test wells were drilled in the Cape Point Area. The test wells were drilled in two general areas (pl. 2) - in a line parallel to the trend of the dunes in the northern part of the area, and in a line extending from the northwestern part of the area to the ocean beach. The sediments penetrated by the test wells may be divided into two lithologic units that are identifiable over all the area covered by test drilling. These lithologic units are shown in cross-section in figure 4.

The upper unit is composed of clean, quartz sand that contains disseminated shell fragments. The upper part of this unit is usually composed of coarse-grained sand which grades downward in size to medium to fine-grained sand in the lower part of the unit. The thickness of the coarse-grained sand in this unit increases toward the ocean beach. Wells drilled near the dunes in the northern part of the area penetrated from 5 to 15 feet of the coarse-grained sand whereas wells drilled nearer to the ocean beach penetrated up to 25 feet of the coarser material. Larger shell fragments are also found in this unit near the beach.

The lower unit is composed of silty sand that was first penetrated in each test well at depths ranging from 30 to 40 feet below land surface. Typically, it consists of medium to fine-grained quartz sands interbedded with thin layers of silt-sized material. Clay layers, indurated shell beds, and lenses of clean sand occur at random in the unit. Well B-11, 153 feet deep, penetrated the entire thickness of this unit that was underlain by a tight clay between the depths of 130 and 153 feet. The other 10 test wells



SECTION SHOWING MATERIAL PENETRATED BY THE TEST WELLS, PRODUCTION WELL, AND OBSERVATION WELLS IN THE CAPE POINT AREA

Figure 4

were drilled to a depth of 128 feet or less and were not deep enough to encounter the tight clay reached in well B-11.

The chloride content of water samples from these wells indicate that the wells drilled near the dunes in the northern part of the area did not penetrate the fresh-salt water interface. Beginning with well B-4 in the line of wells drilled southeastward toward the ocean beach, the fresh-salt water interface was penetrated at increasingly shallower depths toward the ocean (table 2).

Analysis of the test-drilling data indicated that the fresh-water body had the greatest thickness and lateral extent near the dunes in the north-central section of the area of investigation. This area was selected as a potential supply area and a production well (P-1), 3 water-level observation wells, and 1 chloride observation well (O-1, 2, 3, and 4) were constructed (pl. 2).

On March 12 and 13, 1959, a 36-hour pumping test was conducted. Well P-1 was pumped at a steady rate of 70 gpm during the test, and the drawdown in observation wells O-1, O-2, and O-3 caused by pumping was recorded. Field determinations of the chloride content of water samples taken hourly during the pumping test from wells P-1 and O-4 were made by H. B. Wilder, Quality of Water Branch, U. S. Geological Survey.

Well P-1 withdrew water from the clean-sand unit hereafter referred to as the upper aquifer. Ground water occurs in this aquifer under water table, or nonartesian, conditions. Water samples taken from well O-4 during the pumping test for chloride determinations were drawn from the silty-sand unit, or lower aquifer, which contains ground water under semiartesian conditions.

The chloride content of the water from well P-1 ranged from 21 to 16 parts per million during the 36-hour pumping test. During the same period, the chloride content of water from well O-4 ranged from 15 to 18 ppm.

The pumping-test data indicate that the material from which water was withdrawn during the test has a coefficient of transmissibility of about 8,000 gallons per day per foot and a coefficient of storage of about 0.2.

Analysis of the pumping-test data indicate that upward leakage of water from the lower, silty-sand aquifer occurred during the pumping test. It is realized that the coefficient of storage listed

above is probably erroneous owing to this upward leakage. No attempt to determine the error in the coefficient of storage or the amount of upward leakage during the pumping test was made since this information would not apply throughout the potential supply area.

Quality of Water

In ground-water investigations in areas adjacent to or surrounded by salt water, it is a general practice to determine the chloride content of water from wells in the area as a means of detecting salt-water encroachment. During this investigation, ground water with a chloride content greater than 300 ppm was considered arbitrarily to have resulted from some form of salt-water encroachment.

A water sample was collected from well P-1 at the completion of the 36-hour pumping test. A chemical analysis of the water (table 1) indicates a water satisfactory for domestic use with the possible exception of hardness of 183 ppm. The hardness may be reduced by treatment.

Hydrogen sulfide (H_2S), although not present in the water from well P-1, is present in other areas of the same aquifer in concentrations sufficient to impart a disagreeable taste and odor to the water. Hydrogen sulfide may be removed by aeration.

"Safe Yield"

The term "safe yield" as used in respect to the Cape Point Area means the amount of fresh ground water that may be withdrawn in the area, from a well or group of wells, pumped at a constant rate without causing salt-water encroachment.

In an area surrounded by and freely connected with salt water, the lowering of the fresh-water head to or below sea level would in time result in salt-water encroachment if the fresh-salt-water system were in dynamic equilibrium. The elevation of the water level in well P-1 was 9.11 feet above mean sea level before the pumping test was begun. Steady pumping at the rate of 70 gpm for 36 hours drew the water level in well P-1 down by 7.80 feet - or to 1.31 feet above mean sea level. This amount of drawdown would not have been sufficient to have contaminated well P-1 by vertical salt-

Table I - Analysis by Geological Survey, of water from well P-I, Cape Point Area, after 36 hours of pumping at a steady rate of 70 gallons per minute.

(parts per million)

Date of collection - March 15, 1959

Silica (SiO_2)	9.2
Iron (Fe)	.26
Manganese (Mn), dissolved[1]	.01
Calcium (Ca)	68
Magnesium (Mg)	3.2
Sodium (Na)	10
Potassium (K)	.5
Bicarbonate (HCO_3)	211
Carbonate (CO_3)	0
Sulfate (SO_4)	1.7
Chloride (Cl)	18
Fluoride (F)	.2
Nitrate (NO_3)	.1
Phosphate (PO_4)	.3
Dissolved solids	
Sum	215
Residue on evaporation at 180°C	224
Hardness as $CaCO_3$	182
Noncarbonate	9
Specific conductance (micromhos at 25°C)	385
pH	7.3
Color	4
Temperature (°F)	65

[1] In solution at time of analysis.

Table 2 - Chloride content of water in parts per million from the test wells in the Cape Point Area.

Well No.	Total Depth	Chloride content (ppm)	Sample interval (feet below land surface)							
			10-13	20-23	30-33	40-43	50-53	60-63	70-73	80-83	120-123
B-1	123		25		27		28		35	96	
B-2	123		18		18	14	16		14		
B-3	123		16	18		12		28		77	110
B-4	123		30		50	147	1,100	1,140		855	
B-5	63		38	142	206	192	378	3,640			
B-6	53		70	412	1,280	730	1,650				
B-7	33		131	1,750	3,950						
B-8	123		44		29		16		19	16	
B-9	93			30		22		17		16	
B-10	128							133			

water encroachment. However this amount of drawdown should have been sufficient to result in salt-water encroachment in well O-4, but the chloride content of water from well O-4 showed no significant increase during the pumping test. It is apparent that the clay zone penetrated below 130 feet by test well P-11 near the pumping-test site acts as a seal to prevent or, at least, retard the upward movement of salt water in response to a decrease in head.

It is suggested that the yield from individual supply wells should be less than the yield of well P-1 during the pumping test for the following reasons: (1) it is not known whether the clay zone, which apparently acted as a seal to prevent vertical salt-water encroachment during the pumping test, underlies the entire area of investigation, and (2) both aquifers contain salt water in the area that lies between the pumping-test site and the ocean; salt-water could encroach laterally if the cone of depression became too broad and deep.

National Park Service officials desire to locate their ground-water supply system in the dunes along the northern border of the potential production area (pl. 2). Because of the difficulty of entrenching infiltration galleries to the necessary depth (15 to 25 feet) in these dunes, a system of wells is suggested for the area. Evaluation of the geologic and hydrologic data obtained from the test-drilling program and the pumping test suggests that more than 1,000 gpm may be withdrawn safely in the area of investigation if the supply wells are drilled in or near the dunes in the north central section of the area of investigation adjacent to the pumping-test site. The pumping-test data indicate that the yield of individual wells should not exceed 30 gpm and that wells should be at least 300 feet apart and no deeper than 40 feet.

It should be emphasized that the above suggestions are made on the basis of data obtained from a pumping test conducted at one location within the Cape Point Area at a time when the water table was at a high level; they may not be applicable to supply wells in other parts of the area because of lateral changes in lithology or because of a seasonally lower water table. Therefore, all new wells should be pumped before being used as supply wells to determine the rate at which they yield water without causing their water levels to decline below an altitude of 2 feet above mean sea level.

The possibility of salt-water encroachment into the fresh-water supply of the Cape Point Area is a very real and continuing danger; thus measures are necessary to ascertain the early detection of any

such encroachment. The following suggestions are designed to insure early detection of either vertical or lateral salt-water encroachment:

1. The water level in at least one observation well located at least 150 feet from any supply well should be recorded weekly.

2. The chloride content of the water from each supply well should be determined at least monthly.

3. The chloride content of the water from a monitor well located between the supply area and the ocean and screened at the same depths as the supply wells should be determined weekly.

4. Weekly determinations of the chloride content of water from a monitor well in the supply area and screened at least 70 feet below land surface should be made.

These observations should be continued through the first heavy summer pumping season. At the end of this period, the tabulated data may be analyzed to determine the manner in which precautions against salt-water encroachment in the Cape Point Area should be continued.